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1989 Ship Production Symposium

Paper No. 4: Design for Steelwork Production During the Concept Design Phase

U.S. DEPARTMENT OF THE NAVY
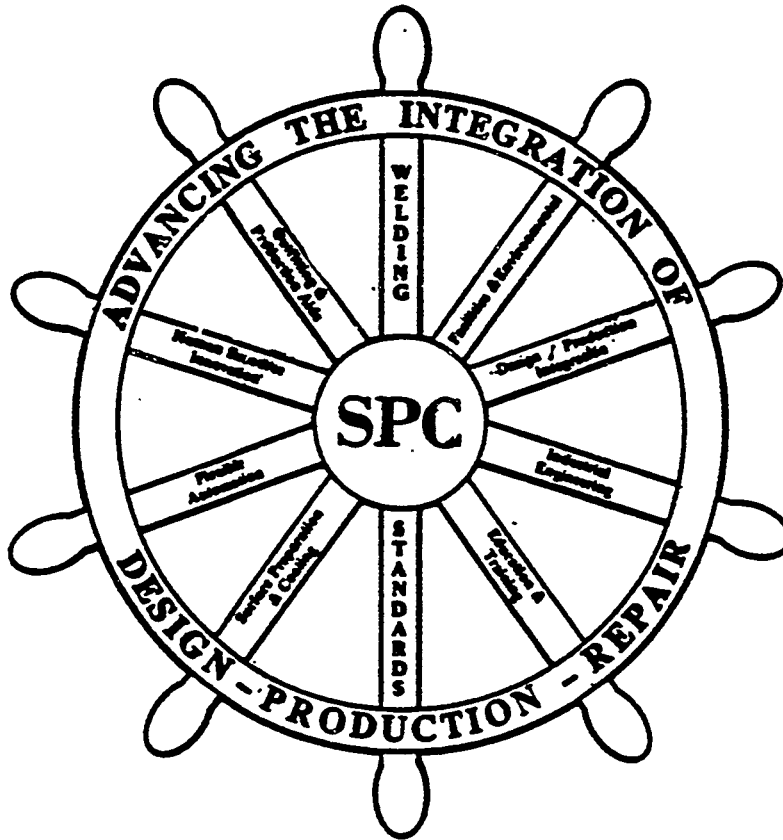CARDEROCK DIVISION,
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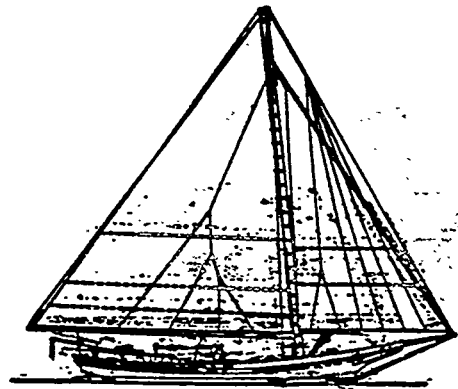
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Design for Steelwork Production During the Concept Design Phase

William Hills, Visitor and **I.L. Buxton,** Visitor, University of Newcastle Upon Tyne, Newcastle Upon Tyne, UK, **Robert G. Maddison,** Visitor, Kvaerner (UK) Ltd., South Shields, UK

ABSTRACT

Methods of improving the level of pre-contract design definition and the quality of information relating to steelwork are described. This information is combined with a comprehensive database of manufacturing process information to provide a system for estimating the work content of the main structural steelwork of ships such as ro-ro vessels. Procedures are described which facilitate consistent estimates to be made while minimizing data handling requirements and increasing the flexibility of the method at the concept design stage.

Applications are described which demonstrate the use of the system in investigations which examine the variation of factors which influence labour cost. The factors examined include the effect of changing midslip block breakdown and length of productive day.

Suggestions are made as to how the system can be used to assess the importance of those factors which may improve overall yard production efficiency and assist in the planning function.

INTRODUCTION

Significant advances have been made in the application of advanced technologies to SKIP design and Calkins (1) provides an excellent overview of progress in this area. This rate of progress has not been accompanied by similar advances in the area of SKIP production in a way which facilitates rigorous analyses of alternative build proposals at the earliest stages in the development of a design. In today's highly competitive market, shipbuilders have to be capable of offering optimum designs, usually implying low construction cost, or at least being able to justify a design at above minimum cost in terms of some special design feature. In addition, the builder has to be confident of the costs estimated, so the methodology used to assess these costs has to be based on sound principles. It is recognised that the new technologies currently used to support ship design activities can be used to improve the builder's ability to assess the effects of different production scenarios on a design proposal. To be effective, a system should provide the capability of assessing different vessel arrangements, variation in hull shape and alternative structural arrangements and build strategies.

Design tools which incorporate production considerations are not generally available, yet there is a clear need for methods which can provide improved levels of reliability and support at the pre-contract stage for those concerned with cost estimating and planning ship production. Developments in ship production methods combined with progress in the implementation of advanced information and resource control systems, e.g. Milne (2) and Vaughan (3), allow the retrieval and capture of production information which is adaptable for use in models which facilitate the estimation of work content and cost.

While it is appreciated that steelwork may not be the most important item wher. considering total ship construction cost, it is the area most under the control of the builder, where production monitoring systems development are most advanced and where reliable information of work content can be most readily determined. Steelwork lies on the critical path for delivery, so early definition is essential. For these reasons, we have chosen to develop a method of estimating the work content and costs of steelwork for use at the earliest stages in the development of a design.

SYSTEM OVERVIEW

It is necessary to be able to estimate the manhours taken to construct a vessel and parts of vessels at various stages of a contract, e.g.

(i) Pre-contract
(ii) Build strategy /orderbook planning
(iii) Departmental/tactical planning
(iv) Workstation loading/operations control.

These stages are often considered as distinct separate activities, usually because the data available increases both in quantity and quality as the contract is worked through. For example very few systems available today facilitate a breakdown of the structure and estimates of joint length to be made at the pre-contract stage. The advantages of making such information available as early as possible are obvious:

```
OUTLINE ARRANGEMENT        STRUCTURAL OUTLINE.        HULL FORM  DESIGN.
      DESIGN.
```

```
                          WORK
                        CONTENT
                      ESTIMATION.
```

FIG (1). MAIN SYSTEM MODULES

EXAMPLE G.A.   SCALE 1 : 550

PROFILE

COMPARTHENTS

```
1   TRAILER DECK
7   DEEP TANK
2   No.4 D.B. CENTRE
3   No.4 D.B. STBD.
4   No.4 D.B. PORT
5   No.2 D.B. PORT
6   No.2 D.B. STBD
```
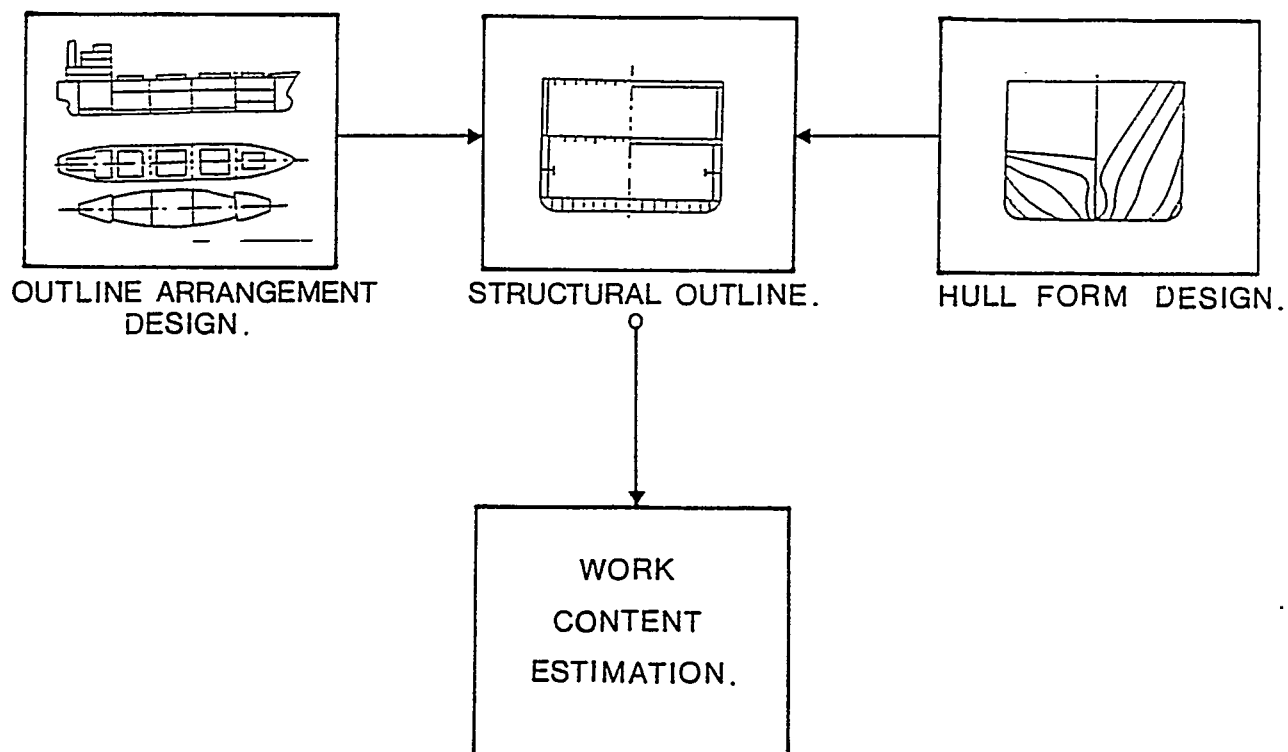
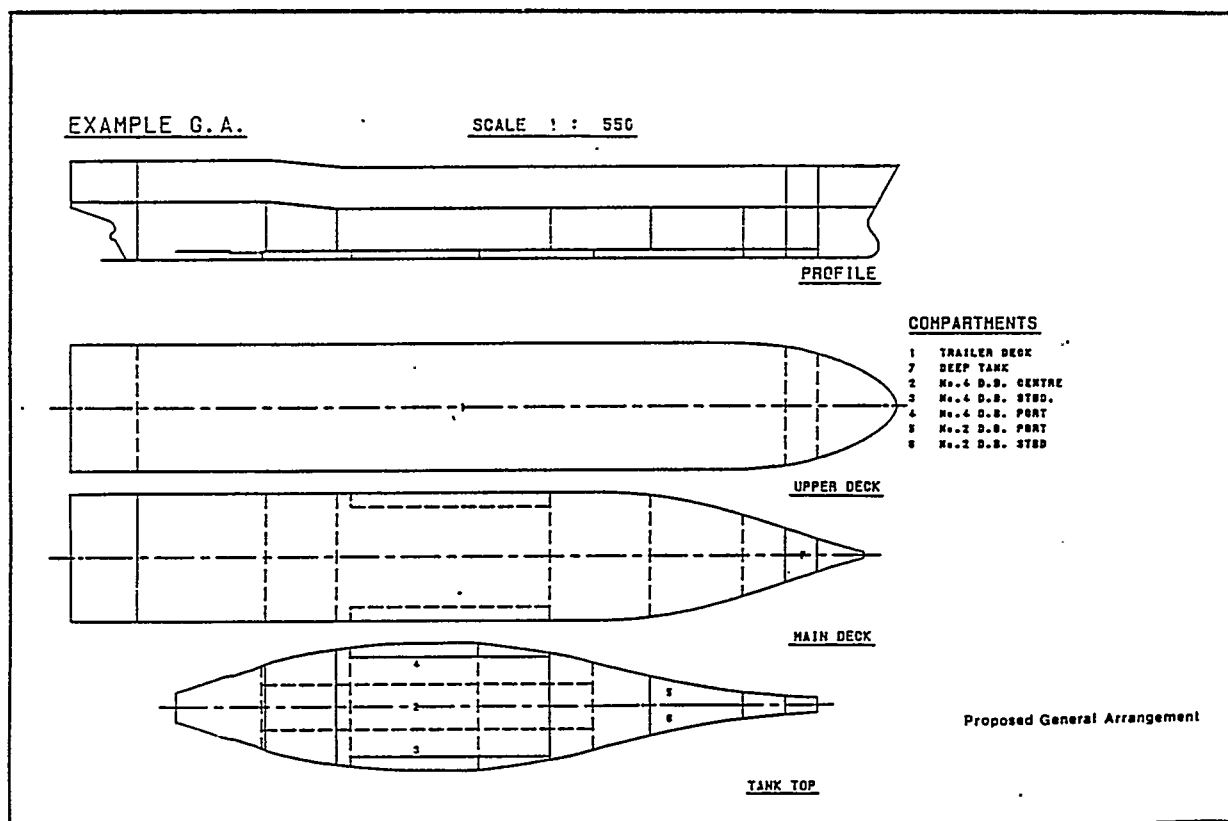UPPER DECK

MAIN DECK

Proposed General Arrangement

TANK TOP

FIG (2). GENERAL LAYOUT OF Ro-Ro SHIP

(i) The designer and production engineer can agree on a build strategy at the earliest stages in the development of the product.

(ii) The implications for planning are significant. The system will be a valuable asset when considering the build strategy. Although the definition of the block breakdown and the related sub-assembly breakdown are associated with the wider aim of maintaining the product work breakdown defined in the shipbuilding strategy, we believe the facility to examine, pre-contract, alternative structural arrangements in this context will be of significant benefit to planners, production engineers and estimators.

(iii) Estimates made of contract manhours at the pre-contract stage can be used to set preliminary manhour budgets and manning levels at workstations. These can then be refined as new, more detailed, information on the ship is developed.

When considering the work content of steelwork, the preferred parameter is manhours per metre of joint length. In the past parametric methods were used which led to the evaluation of global measures of merit in which production costs were usually evaluated using weight as a basis. It has been recognised that methods based on costs evaluated through the estimation of joint length offer a more rational approach: Winkle [4], Bong [5], Brown [6]. The difficulty has been in estimating early in the design process the various joint lengths consistently, rather than just relating to some simple parameter such as weight. However no attempt has been made to develop a system which extends these principles to the ship as a whole, including the ability to take into account alternative build strategies, differing vessel arrangements and hull shape.

These are features which require consideration at the concept stage, where the search for improvement requires a number of alternative designs to be generated and assessed rapidly and accurately. Fortunately research carried out by the authors has produced a design system which can generate useful information specifically developed for use at the concept or pre-contract stage. Fig.(1) shows the main modules of the system upon which the work content estimation process depends. The structure of the system enables comprehensive information regarding shape, layout, structure and scantlings to be provided directly to the cost estimating module.

Links with the Design Process

Hills and Buxton [7] have described a design system which incorporates features which utilize the attributes of artificial intelligence, graphics and database technology. It is sufficient for the purpose of this present paper to indicate the type of data available via such a system to the estimator or planner when assessing work content. This includes:

(i) A hull form incorporating any special features

(ii) An outline general arrangement and principal compartmentation information, e.g. Fig.(2).

(iii) Main structural layout and scantlings at principal sections, Fig.(3).

(iv) Steelmass estimate and distribution along the length.

(v) Preliminary checks on: trim, stability, strength, power, motions etc.

The availability of this information at the concept or pre-contract stage at an appropriate level of definition and accuracy within about a day or so of making a
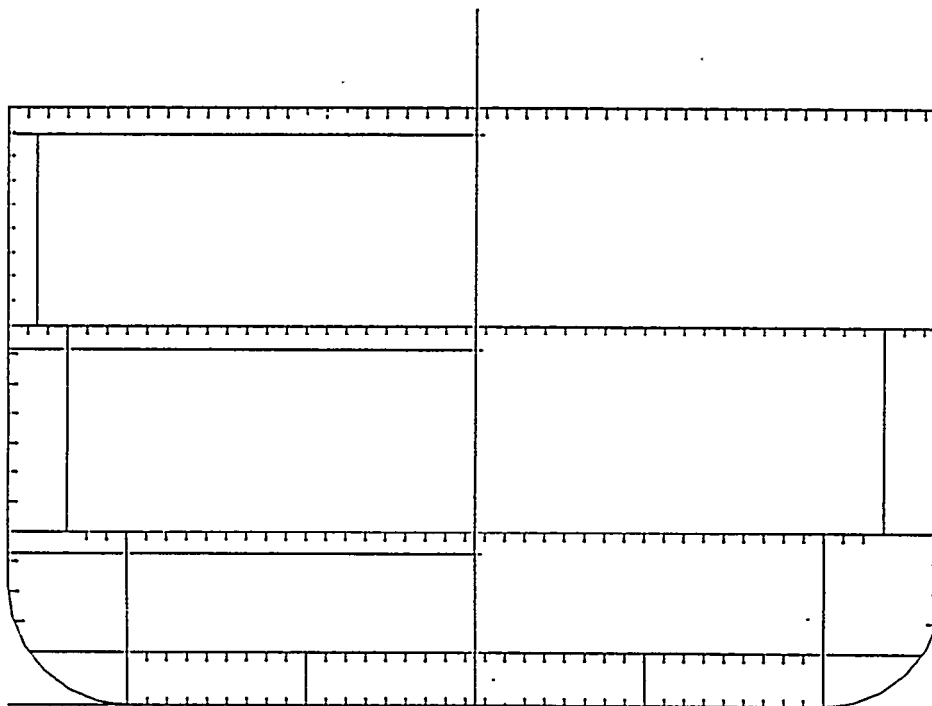

FIG (3). STRUCTURAL LAYOUT

sketch of the design is a significant advance which allows variations to be explored, so that a tender can be prepared with a higher level of confidence. It is possible to use the cost estimating module in a stand-alone mode. In this case the user would simply input information (which had been obtained from alternative sources) under (i) to (iii). A particularly useful application is to consider the midship section only. By doing so a series of sensitivity studies can be carried out in the minimum of time. This mode of application will be demonstrated later in this paper. The ability to estimate scantlings is a necessity if steelwork process analysis data is to be used effectively in the estimating process, since consistent measures of work content are the key.

Determination of Scantlings and Steelmass

The adopted approach requires a reasonably complete internal layout definition, showing decks, bulkheads, hull form and other structural details such as pillars or inner skin. From this information and the applied cargo loadings, the spans of each member are found and the scantlings determined. Most of the scantlings are determined according to the Steel Ship Construction Rules for General Cargo Ships defined by Lloyds Register of Shipping. Whale the scantlings are generated consistently, and give an indication of a likely value, it must be emphasised that they are not necessarily final approved values.

The system as developed at present will cater for most types of cargo roll-on/roll-off vessels but not those parts of the ship with cellular container holds. It will also cater for ferries up to the uppermost continuous deck. In principle it will cater for other multi-deck ships not having large hatchways, where the layout and loading of decks can be converted into the equivalent 'ro-ro' input.

Since the scantlings of such ship types as ro-ro ships are significantly affected by the number, height and loading on each deck, special attention is paid to their structure. Vehicle loads are used to assess the basic deck structure, but deep beams and web frames are estimated from an abbreviated finite element calculation.

Due to the variability of possible internal layouts and range of user-defined hull sections, the extent of the results output can vary. A typical ro-ro layout is drawn in Fig.(3). Broadly speaking the following informat ion is generated as output:

(a) Approximate deck scantlings
approximate bottom scantlings
approximate side shell scantlings
(b) steelmass rates, V. C. G., components and local dimensions of:-
(i) decks
ii) bottom
iii) side shell
(c) graphical bar chart of hull section rates along the length
(d) mass rates and V.C.G. summary
(e) main hull steelmass (structure) total and distribution
(f) ship extremity mass estimates
(g) transverse bulkhead masses
(h) superstructures
(i) graphical plot of cross-sections
(j) alternative ship depths or clear deck heights on ro-ros.

A typical example of part of the output is shown in Fig.(4).

The availability of this data which gives number, spacing, length and scantlings of the main steelwork components, together with the graphics capability of modern engineering computer workstations, provides the ship designer and production engineer with a powerful product development aid. The place of the scantling and steelmass module within the cost estimating process is indicated in Fig.(5).

WORK CONTENT AND COST ESTIMATING

Some other industries are much more advanced than shipbuilding in not only establishing work content associated with different equipments and construction processes, but in publishing data (8). In the absence of published data for shipbuildmg, it is necessary for each company to establish (e.g. by work study) a database of unit times for principal activities of the construction process, which are compatible with the technical description of the hull. In the case of hull structure, it is therefore necessary to be able to break the main portion of the hull into units from which work content can be generated for each of the three principal workstations:

(1) Preparation (shotblasting, priming, marking, burning, rolling)
Number, areas and perimeter of plates and sections, flat or curved.
(2) Fabrication (construction of sub-assemblies and panels, and welding into units or blocks).

For generic 2D and 3D units, and their panels, units and connections; joint length of plates, sections and associated thicknesses and number of parts.

(3) Erection (transporting, lifting, fairing, tacking and welding at the berth).
Number, weight, 2D or 3D Hat or curved, perimeter joint length, position and access, free-standingness.

Generic Units

The level of detail being considered results in large numbers of structural items being generated by the system. Clearly the problems of handling such large amounts of data are considerable, particularly when the necessity for rapid computer response times is paramount. Large numbers of alternative types and arrangements of units can be defined when considering a build strategy for a ship. At the concept stage these

	mass t	rate	vcg m	bth m	t mm	l m	
TANK TOP PLATE=	7.33	2.89	1.50	22.99	16.0	2.54	

	mass t	rate	vcg m	dw mm	tw mm	ff	tf mm	l m	No.
CENTRE GIRDER =	0.40	0.16	0.75	1500.	13.	0.	0.	2.54	1
SIDE GIRDER =	1.18	0.46	0.75	1500.	10.	0.	0.	2.54	4
FLOOR =	3.02	1.19	0.77	1500.	12.	0.	0.	22.99	1
FLOOR STIFFS =	0.42	0.16	0.75	163.	11.	0.	0.	1.00	30
BILGE BRKTS =	0.74	0.29	0.75	1500.	12.	0.	0.	1.81	6
BOTTM LONGL,S =	1.60	0.63	0.11	220.	9.0	bulb	flat	2.54	30
T.TOP LONGL,S =	2.72	1.07	1.36	280.	12.0	bulb	flat	2.54	30
BOTM/BLG SHL =	5.94	2.34	0.12	t= 13. mm					
BOTTOM TOTAL =	23.36	9.20	0.86						
Tank Top load=	6.50 t/m2	spacing=	550. mm						

SIDE SHELL PLT

	mass t	rate	vcg m	t mm	bth m	l m
STRAKE	1.08	0.43	2.79	10.5	2.54	2.59
STRAKE	2.06	0.81	6.54	10.5	2.54	4.91
STRAKE	2.03	0.80	11.82	9.0	2.54	5.65
STRAKE	0.92	0.36	15.50	13.5	2.54	1.70
SIDE SHELL =	6.08	2.40	8.98			

DECK DATA

MAIN DECK   Load= 2.50 t/m2   spacing= 550.mm. shell frm spacing= 635.mm

	mass t	rate	vcg m	t mm	bth m	l m			
PLATE =	7.34	2.89	9.00	16.0	23.00	2.54			

	mass t	rate	vcg m	dw mm	tw mm	ff mm	tf mm	l m	No.
DECK BEAMS =	3.69	1.45	8.55	900.	13.	350.	25.	23.00	1
DECK LONGLS =	3.29	1.30	8.85	300.	11.0	bulb	flat	2.54	37
INNER HULL =	8.57	3.37	5.15	2500.	11.	2540.	12.	7.50	2
.SIDE FRAMES =	2.67	1.05	5.25	400.	14.0	bulb	flat	7.50	6
DECK GIRDERS =	1.62	0.64	8.55	900.	10.	600.	30.	2.54	3

UPPER DECK Load= 1.50 t/m2   spacing= 600.mm. shell frm spacing= 635.mm

	mass t	rate	vcg m	t mm	bth m	l m			
PLATE =	7.34	2.89	16.35	16.0	23.00	2.54			

	mass t	rate	vcg m	dw mm	tw mm	ff mm	tf mm	l m	No.
DECK BEAMS =	3.20	1.26	15.98	750.	12.	350.	25.	23.00	1
DECK LONGLS =	2.93	1.16	16.20	300.	11.0	bulb	flat	2.54	33
DEEP FRAMES =	1.96	0.77	12.30	850.	12.	350.	25.	6.60	2
SIDE FRAMES =	1.19	0.47	12.68	240.	10.0	bulb	flat	7.35	6
DECK GIRDERS =	0.59	0.23	15.98	750.	10.	200.	12.	2.54	3

TRANSVERSELY FRAMED   FLOOR SPACING   2.540 metres

SUMMARY OF HULL SECTION
******ᐧ*****************************

Item	tonnes	tonne/metre	VCG m	clr ht.blw m	Hght a.b. m
ᐧ******************ᐧ*****-					
DOUBLE BOTTOM	23.36	9.20	0.86		
DECKS					
MAIN DECK	15.94	6.27	8.82	6.56	9.00
UPPER DECK	14.07	5.54	16.22	6.56	16.35
SIDE	20.48	8.06	7.42		
TOTAL	73.84	29.07	7.33		

FIG (4). PART OUTPUT FROM SCANTLING AND MASS ESTIMATION MODULE

```
┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
│   ┌─────────────────────────────────┐ │
│   │ Generate structural layout & scantlings │
│   └─────────────────────────────────┘ │
│                  │                     │  Scantling
│                  ▼                     │      &
│   ┌─────────────────────────────┐     │  steelmass
│   │ Display section outline & define │ │  module
│   │   required block breakdown   │     │
│   └─────────────────────────────┘     │
└ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
```

```
            ┌──────────────────────────────────┐
            │ Obtain list of structural items in each unit │
            └──────────────────────────────────┘
                          │
                          ▼
┌──────────────┐  ┌──────────────────────────────┐      ┌──────────────────┐
│ Redefine unit │◄─│ Check against generic units for match │◄────►│ Data base of     │
└──────────────┘  └──────────────────────────────┘      │ generic units    │
                          │                              └──────────────────┘
                          ▼
              No      ◇ Match achieved ◇
         ◄────────────
                          │ Yes
                          ▼
            ┌──────────────────────────────────┐
            │ Calculation control:             │
            │ Assemble dimensions, part nos., type etc. │
            └──────────────────────────────────┘
                          │
                          ▼
            ┌──────────────────────┐
            │ Calculate joint lengths │
            └──────────────────────┘
                          │
                          ▼
            ┌──────────────────────────────────┐
            │ Identify operations to be performed by │
            │           workstations:          │
            │ 1. Preparation 2. Fabrication 3. Berth erection │
            └──────────────────────────────────┘
                          │
                          ▼
            ┌──────────────────────────────────┐      ┌──────────────────┐
            │ Determine work content standard manhours │◄──│ Manufacturing process │
            └──────────────────────────────────┘      │   data base      │
                          │                            └──────────────────┘
                          ▼
            ┌──────────────────────────┐      ┌──────────────────┐
            │ Determine inherent manhours │◄──│ Standard to inherent │
            └──────────────────────────┘      │   allowances     │
                          │                    └──────────────────┘
                          ▼
            ┌──────────────────────────┐      ┌──────────────────┐
            │ Determine predicted manhours │◄──│ Efficiency factors to │
            └──────────────────────────┘      │ convert to predicted │
                          │                    │   manhours       │
                          ▼                    └──────────────────┘
            ┌──────────────────┐      ┌──────────────────┐
            │  Convert to cost │◄──│  Unit costs of   │
            └──────────────────┘      │ labour & materials │
                                      └──────────────────┘
```
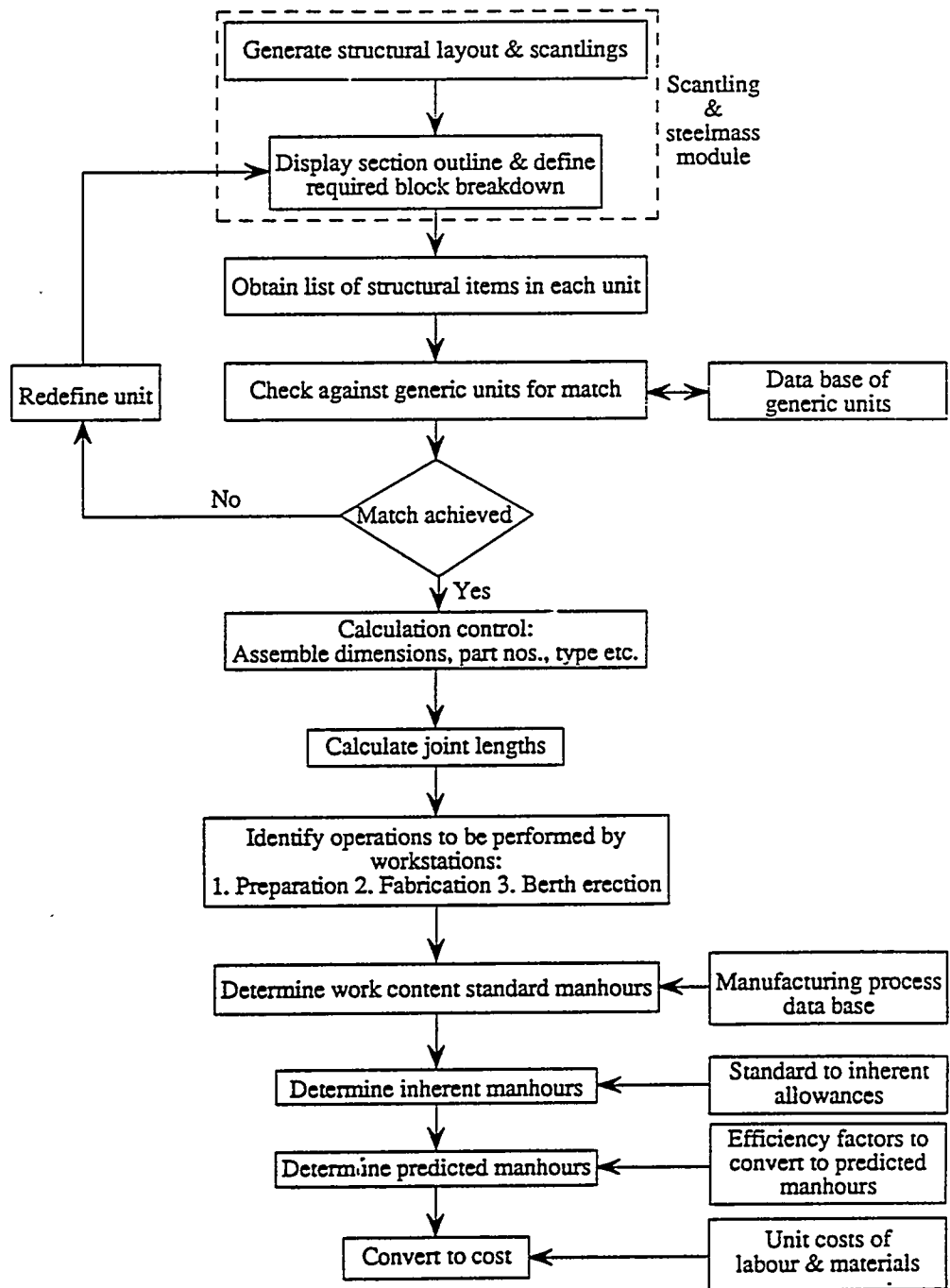
FIG (5). SCHEMATIC OF COST ESTIMATING PROCEDURE

problems can be overcome, without seriously reducing the accuracy and flexibility of the system, by introducing the concept of 'generic units'.

An examination of a range of ship types shows that the structural arrangement of a ship is composed of stiffened panels composed of flat or curved plates to which are welded frames, beams, longitudinals, girders etc. These in turn are joined to make units or blocks of which there are about two dozen basic or 'generic' types. Each generic unit is further sub-divided according to whether each panel is flat or curved, longitudinally or transversely framed etc. For a specific ship type it is usually possible to define a realistic structural arrangement using a sub-set of these generic units. Table (1) gives a list of those used to define Ro-Ro ship structures. Fig.(6) illustrates the arrangement and composition of typical generic units.

Table 1
MENU OF GENERIC UNITS (Ro-Ro Type)

(1) Flat or Curved Panel with associated stiffeners
(2) L-Unit Flat or Curved (e.g. deck plus side panel)
(3) L-Unit with Inner Hull.
(4) C-Unit Flat or Curved (e.g. deck plus two side

(5) C-Unit with Inner Hull
(6) F-Unit Flat or Curved (e.g. two decks plus side

(7) F-Unit with Inner Hull
(8) F-Unit with Lower Inner Hull
(9) Double Bottom Unit - Full breadth, 5 girders
(10) Double Bottom Unit - Full breadth, 3 girders
(11) Double Bottom Unit - Flat with 3 girders
(12) Double Bottom Unit - Flat with 1 girder
(13) Double Bottom Bilge Unit - 1 side girder
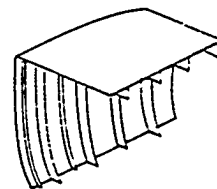(14) Double Bottom Bilge Unit - 2 side girders

A generic unit can be considered as a 'macro' in computing terms, so has a limited number of defining parameters and possible construction processes. Program development has been facilitated by limiting the potentially infinite number of possible constructional arrangements to generic building blocks which are typical of practical shipbuilding.

Using his knowledge of the range and form of available generic units, the designer/planner is able to divide the hull into a number of blocks which represent a possible build strategy, Fig.(7). The dimensions of a unit are compared against the maximum dimensions that the facility can handle and against defined 'preferred dimensions'. For example the unit length is checked to ensure that it is a multiple of the deep frame spacing and that it is less than or equal to the maximum plate length which has been defined as a yard standard or as a preferred plate size. The availability of weight data also allows the total weight of a unit to be compared against the maximum lifting capacity. Once the user has defined a unit envelope, the system interrogates the structural database and assembles a list of items which exist within the envelope boundaries. The list
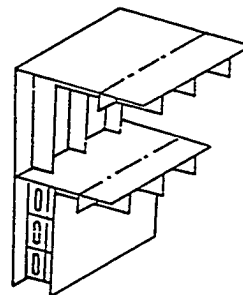
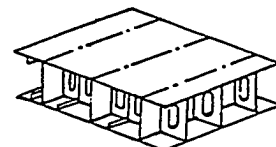Fig.6 — EXAMPLES OF GENERIC UNITS.

L - Unit.
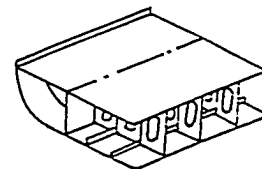Side Shell and Deck Panel.

F - Unit.
with Lower Inner Hull.

Double Bottom.
Centre Unit – Flat 3 Girders.

Double Bottom.
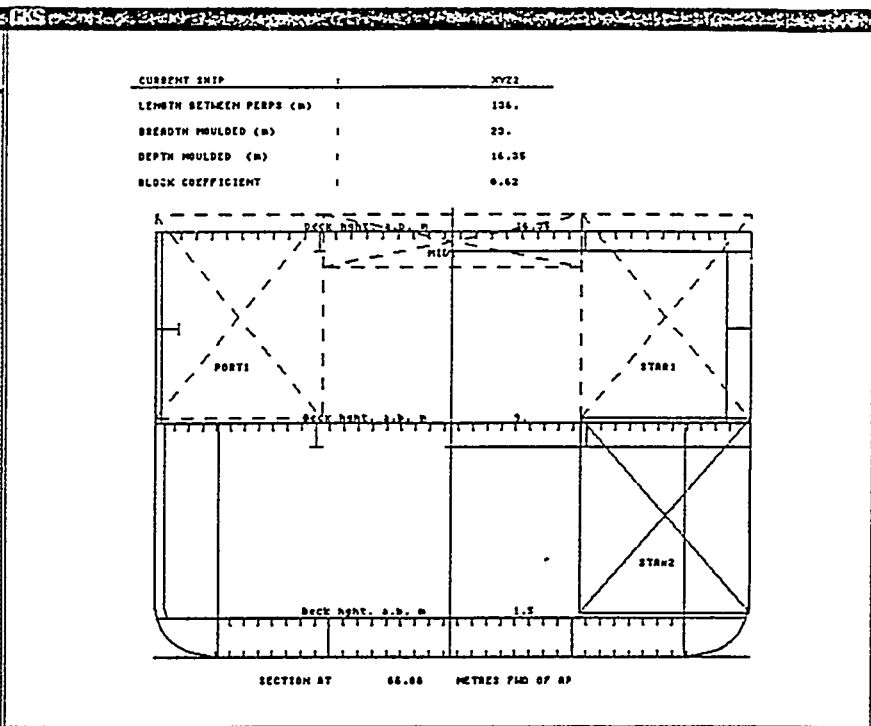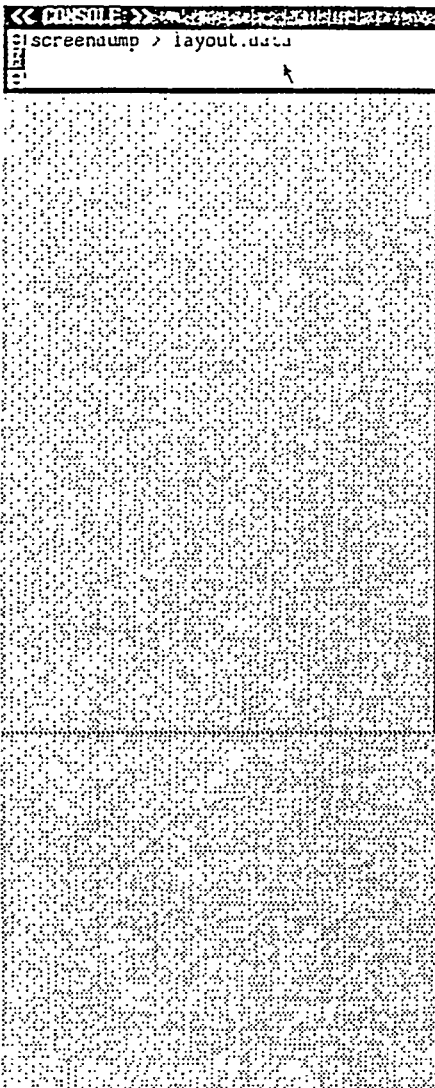Bilge Unit – 1 Side Girder.

of items is checked against the list of structural items which are used in the definition of each generic unit. If a match is not found, a message appears on the screen and the user is invited to re-define the boundaries of the unit under consideration. When a unit has been successfully defined and matched, the output from the scantling and mass estimation program is accessed to pick out the geometry and scantlings associated with each panel, e.g. plating thickness, stiffener type, spacing and dimensions.

The procedure by which a match is made between the user defined unit and the data bank of generic units is as follows:

(i) The structural data base is interrogated to identify the structural items which lie within the defined boundaries.
(ii) The program creates a list of items for the Unit, each item being represented by a number.
(iii) Using an indexed search technique, this list of numbers is checked against the stored sequences that predefine each generic unit.
(iv) When a comparative list of items is found, the structural routine is invoked and the work content parameters are generated.

An example of a typical record for a generic unit is shown in Fig.(8). This is for a 'L' unit, e.g. deck and side shell. It can be seen that the match has been made on the list of items where

CURRENT SHIP : XYZ2
LENGTH BETWEEN PERPS (m) : 136.
BREADTH MOULDED (m) : 23.
DEPTH MOULDED (m) : 16.35
BLOCK COEFFICIENT : 0.62

SECTION AT 66.00 METRES FWD OF AP

NOTE axis are:- NEGATIVE to PORT of CL
POSITIVE to STARBOARD of CL

INPUT THE LEFT HAND SIDE OF UNIT " STAR2 " looking fwd about CL m ? 5
INPUT THE RIGHT HAND SIDE OF UNIT " STAR2 " looking fwd about CL m ? 11.5
INPUT THE HEIGHT a.b. OF THE BOTTOM OF UNIT " STAR2 " m ? 1.7
INPUT THE HEIGHT a.b. OF THE TOP OF UNIT " STAR2 " m ? 9.2

INPUT CORRECT (Y/N) ? Y

RE-DEFINE THE CURRENT OR A PREVIOUS UNIT Y/N ? ☐

FIG (7). MIDSHIP SECTION SHOWING PARTIAL BLOCK BREAKDOWN

```
* GENERIC UNIT TYPE         SPECIFIC UNIT
*
* L Units                   Deck & side shell: curved, longl framed
*
       2                            1
*
* NO. FOUND   NO.GENERATED    NO. GENERATED    NO. GENERATED
*             (PREPARATION)   (FABRICATION)   (BERTH ERECTION)
    7              10              17               12
*
* SEQUENCE FOUND
 0 1 2 3 16 18 22
*
* SEQUENCE GENERATED (PREPARATION)
 0 1 2 3 7 8 16 18 22 38
*
* SEQUENCE GENERATED (FABRICATION)
 0 1 2 3 4 5 6 7 8 16 18 22 27 35 36 37 38
*
* SEQUENCE GENERATED (BERTH ERECTION)
 9 10 11 12 13 14 28 29 30 31 33 91
*
```

FIG (8). STRUCTURAL ITEMS IDENTIFIED BY WORKSTATION FOR GENERIC UNITS

0 = Deck Plate
1 = Deck Beams
2 = Deck Longitudinals
3 = Deck Girders
16 = Side Shell Plate Curved
18 = Deep Web Frames Curved
22 = Side Longitudinals Curved

However the record also shows an extended list for each workstation, i.e. complete construction 'sequence generated'. These additional items cater for processes implicit in the assembly operations but not explicitly defined by the structural routine. For example in the fabrication of the 'L' unit, these are:-

4 = Beam/Longitudinal Interconnections
5 = Beam/Girder Flange Interconnections
6 = Beam/Girder Butt Interconnections
7 = Beam/Girder Gussets
8 = Beam Tripping Brackets
27 = Deep Frame/Side Longitudinal Interconnections
35 = Deck/Side Shell Interconnections
36 = Deep Frame/Beam Interconnections
37 = Beam/Side Shell Interconnections
38 = Deep Frame/Beam Bracket Interconnections

While these items are not calculated 'strucuture' and may not have weight, they do have the other attributes of structural items such as: joint length, thickness and number and they therefore have a work content associated with them.

When a defined unit has been accepted and the appropriate workstation identified, the program calculates the work content parameters for each item in the list. Each item in a panel is then associated with a pre-determined manufacturing process module, which is part of a comprehensive process analysis database, which identifies the steelworking processes necessary to prepare and fabricate it, in terms of workstation, equipment needed, joint type and sequence of construction. The work content database (which can be modified by the designer) is then accessed to pick out the standard time for each process invoked.

The work content database

The original work content data base was developed after extensive work study operations in British Shipbuilders Govan Shipyard at Glasgow. In essence the database consists of the standard times necessary to carry out an operation. The 'standard time' is the time in which a task should be completed by a worker at normal performance as defined in British Standards and described later. The range of operations contained in the current data are given in Table (2). A typical record for an operation is shown in Fig.(9).

The items are identified via the models of the assembly/fabrication process in which the sequence of the work process has been modelled for each generic unit and thus, implicitly, for the defined unit. This model of the assembly/fabrication process together with the

information on joint length, thickness, number of piece parts etc. allows the work content to be determined. The joint length is the physical connection length , irrespective of the number of weld passes needed to complete it.

Table 2 - WORK CONTENT DATABASE

1 Manual butt weld downhand restricted
2 Manual butt weld downhand unrestricted
3 Manual butt weld downhand and overhead restricted
4 Manual butt weld vertical restricted
5 Manual butt weld vertical unrestricted
7 Manual butt weld overhead restricted
10 Manual butt weld horizontal restricted
11 Manual butt weld horizontal unrestricted
13 Manual fillet weld downhand restricted
14 Manual fillet weld downhand unrestricted
15 Manual fillet weld vertical restricted
16 Manual fillet weld vertical unrestricted
17 Manual fillet weld horizontal restricted
18 Manual fillet weld horizontal unrestricted
19 Automatic butt weld seam constant
20 Automatic butt weld welding constant
21 Automatic fillet welding
22 Automatic butt weld seam constant
23 Automatic butt welding constant (one side)
25 Fair and tack T-Section restricted (positioned manually)
26 Fair and tack T-Section unrestricted (positioned manually)
27 Fair and tack T-Section restricted (positioned by crane)
28 Fair and tack T-Section unrestricted (positioned by crane)
29 Fair and tack longl or frame (OBP - straight) unrestricted
30 Fair and tack longl or frame (OBP - CURVED) unrestricted
31 Fair and tack flat plate butts
32 Fair and tack curved plate butts
50 Berth erection type 1 unit
51 Berth erection type 2 unit
52 Berth erection type 3 unit

Once a generic unit has been identified and the manufacturing information generated at each of the three main workstations, the work content estimation algorithms are invoked. For each structural item within a unit, e.g. deck girder, a manufacturing process code is applied. For example, at fabrication of deck girders, processes include from Table 2:

28 Fair and Tack T-section unrestricted, positioned by crane
21 Automatic fillet welding.

In turn these operations are associated with the length and thickness of each particular girder. By looking up in the appropriate work content database record similar to Fig.(9), the basic and hence the standard minutes can be calculated.

```
MANUAL BUTT WELD DOWNHAND UNRESTRICTED CONSTANTS (MBWDUC)
----------------------------------------------------------

ARRAY POINTER    SIZE
       2           20

Std. Global       Basic Global
Job Constant      Job Constant      (in minutes)
     16.5             12.29

 Std. Lifting &    Basic Lifting &
Turning Constant  Turning Constant   (in minutes)
     12.12             9.18

Std. Section      Basic Section
  Constant          Constant        (in minutes)
     0.0               0.0

RATE: Std Min/mtr    BASIC Min/mtr   PLATE THICKNESS ('T' mm)
                                       lower < T <= upper
**********************************************************************
        53.96           11.34          0.0      8.0
        63.73           24.41          8.0     10.0
        67.70           27.29         LO.0     11.0
        76.62           33.79         11.0     13.0
        77.64           34.51         13.0     14.0
        86.39           40.89         14.3     16.0
        96.69           48.35         16.0     18.0
       107.03           55.88         18.0     19.0
       119.42           64.93         19.0     20.0
**********************************************************************
   'K' PREPARATION ABOVE
   'M' PREPARATION BELOW
**********************************************************************
        74.17           53.08         20.0     22.
        83.02           59.35         22.0     23
        94.88           67.26          5        2
       106.11           75.72
       117.16
       130.80
       144.03
```

FIG (9). RECORD FROM WORK CONTENT DATA BASE FOR ONE PROCESS

Such calculations are made using a 'standard algorithm which allows for the appropriate coefficients to be automatically selected according to the structural item, processes and thickness. Thus standard minutes for deck girder fabrication are calculated in the form of:

Global Job Constant Process 28 + Global Job Constant Process 21
+ Section Constant for Process 28 x Number of Sections [2 for web plus flange]
+ (Minutes per Metre Process 28 + Minutes per Metre Process 21) x Piece Part Assembly Joint Length [Flange welded to web].

A similar calculation is made for welding the fabricated girder to the deck plating using Panel Fabrication Joint Length. Each element is adjusted if necessary for actual manning if different from standard manning levels and then converted to manhours. It can also be multiplied by a process efficiency factor if the actual process in the shipyard differs from the standard assumed.

Comparable algorithms are used at Preparation and at Berth Erection workstations using the appropriate processes and work content parameters.

ESTIMATING OVERALL STEELWORK MAN-HOURS

The basis of the standard manhour estimate is the structural definition generated by the scantling and steelmass program and the unit breakdown as input by the user. At the preliminary design stage, it is not possible to specify every item of structure in complete detail, for example, cut-outs in floors, so that it is necessary to make allowances for such elements which are inherent in any as-built structure. Thus standard manhours are converted to inherent manhours according to type of generic unit and the relevant workstation.

The inherent manhours reflect the work content built-in by the structural designer and the proposed build strategy. In an ideal world, inherent manhours would be the same as actual manhours, but there are many reasons why actual hours will be signficantly higher. Elements such as rework percentage. effective use of the working day or material control efficiency all add to the manhours recorded for actual ships. Thus factors which are specific to a particular shipyard and its management need to be added to obtain predicted manhours as a realistic estimate of Actual manhours.

Standard Time

Standard times have been derived from work study data, so represent the average time that a qualified worker should take, using the specified method and proper motivation. Normal relaxation and contingency allowances are included to account for 'legitimate' extra time to add the basic process time. The user may build into the database additional factors to allow for process efficiencies different from the standard. For example a particular process may use a more efficient method than incorporated in the database (e.g. laser cutting of thin plate, whale the actual manning level of this process may require a different number of operators to that assumed.

Inherent Time

At each of the workstations, it is necessary to make allowances for additional operations that are not explicitly included in the hull definition. At the preparation stage, for example, burning lengths calculated for bare plates need to be increased for (undefined) cut-out lengths. At fabrication, minor brackets and stiffeners need to be allowed for on top of the main structural elements. If any outfit structure such as seatings are being added at this stage, the factor can be adjusted, although it is probably better to keep such items separated from main structure in the estimate.

At berth erection, the basic process of say butt welding of adjacent panels uses the standard database for type of weld and thickness. Allowances need to be made for the location of the unit on the berth and access thereto, whether it is a 2D or 3D unit, as well as the overall weight in terms of extra time to transport and lift. Thus for berth erection, a typical form of Standard to Inherent calculation for a particular generic unit is:

Inherent manhours = Standard manhours **(1 + access** factor)

> + Berth erection joint length x 2D/3D factor
> + Unit weight x weight factor

The database containing default values may be adjusted by the user.

Inherent time reflects on a consistent basis differences in work content arising from the way the structure has been designed and the proposed breakdown of units. Thus it can be used to compare the 'efficiency' of alternative strategies.

Predicted Time

Predicted time has to incorporate all those efficiencies which are not inherent in the technical specification, but reflect the success (or otherwise) of a particular shipyard's management in controlling all the ways in which jobs take extra time. Anyone who has worked in a shipyard will recognise that the number of hours booked to a job will be higher than the somewhat idealised inherent hours due to:-

poor plant layout resulting in additional time to transfer men and components between workstations

inadequate cranage resulting in extra time to lift and move units

environmental conditions, e.g. bad weather in terms of wind, rain or temperature delaying activities. An open facility in a bad weather region will lose more time than a covered facility, but less so in a good weather region.

rework, due to poor accuracy control or distortion, e.g. cutting and trimming units

poor time-keeping. Late starting and early finishing is not unknown in shipyards

official and unofficial breaks for meals, refreshments etc, reducing the effective working day

material control efficiency, reflecting the ability to ensure that labour is not held up waiting for materials

labour control efficiency, to ensure that work, especially on the critical path, is not held up for lack of labour, either of any type, or of a specific type, e.g. due to trade demarcation

excess manning levels. A yard may allocate more men to an activity than is strictly necessary, perhaps as a result of trade union pressure, or 'using' surplus manpower.

shipyard loading. It is not always possible to match the workload to the available labour, particularly as order books run out, when the tempo of work may also slow down.

In the program, these factors are incorporated in a number of factors:-

Generic Unit or Workstation

(i) Plant layout factor
(ii) Environmental factor
(iii) Rework factor
(iv) Labour application factor
(v) Waiting factor

Global Shipyard Factors

(vi) Effective working day factor
(vii) Manning level factor
(viii) Shipyard loading factor

(i) Covers deviation from ideal flow-line layout
(ii) Varies between workstations; obviously shipyard location specific
(iii) Rework includes a factor to allow for cutting and edge correction particularly at berth erection. It depends on the ability of the yard, together with its accuracy control procedures, to produce structural components within acceptable tolerances. There is a separate allowance of manhours per square metre to allow for distortion correction which is a function of panel area and generic unit.
(iv) Labour application factor depends on the effectiveness of management and supervision in ensuring that the correct labour is available at the correct time and working properly.

(v) Waiting factor allows for delays where labour is waiting for materials, services, information or due to equipment breakdown.

The remaining three factors can be expected to apply across the entire shipyard at any given time. They are essentially self-explanatory, and applied as global factors to the total manhours.

The importance of the above eight factors should not be underestimated, since they are cumulative. For example, if one postulates the following values for each factor (averaged across units):

(i) 1.05 (ii) 1.10 (iii) 1.30 (iv) 1.15 (v) 1.20 (vi) 1.25 (vii) 1.15 (viii) 1.00

this gives an overall factor of 2.98. Thus three times as many hours have to be paid for as are technically required. Furthermore, elapsed build time is likely to be longer (though not proportionately) and direct overheads will be incressed.

In practice, the elements are estimated on the basis of techniques such as activity sampling and rework measurement, plus professional judgement. In particular areas, overall Inherent to Actual factors as low as 1.5 and as high as 6 have been found. It is also desirable to check the overall factors from completed units in a specific shipyard so that individual factors can be tuned on a heuristic basis to give consisent results. The factors do of course highlight areas where the most managerial attention should be paid. Broadly speaking, poor performance shipyards will get a better return from controlling the above factors than installing new equipment, where the latter mainly affects Standard Time rather than Actual Time.

APPLICATIONS AND DISCUSSION

To illustrate the use and capabilities of the system a basis ship is selected. The vessel is a 7500 tonne deadweight, two-deck ro-ro ship, with an inner hull in the lower hold. The principal dimensions are:

Length B.P.	136.0m
Breadth moulded	23.0m
Depth moulded to upper deck	16.4m
Depth moulded to main deck	9.0m
Design draught	6.9m
Block coefficient	0.622
Scantlings	See Fig.4 for estimated data

The main benefit of the new system is that it enables the designer to investigate the effects of possible changes in structural configuration, production facility capabilities and workstation parameters. To illustrate this capability, examples are given in which the following are examined: changes in the number of units used to construct the midship region and the effects of variation in length of productive day.

Effect of Change in Unit Configuration

One of the most important decisions to be made when developing a design concept is to determine the unit or block breakdown which is compatible with the available production facilities and is capable of being produced efficiently at minimum cost. One stage in the investigation might be a comparison of alternative unit breakdowns on a basis of minimum cost of labour plus material, while satisfying the maximum lifting capacity at each workstation. To illustrate this approach, three alternative unit configurations were generated, consisting of 3, 6 and 9 units respectively, which are shown in Fig.(10). The joint lengths, work content and labour cost estimates, are generated. A typical output for a 'C' unit at the fabrication workstations is shown in Fig.(11) and a summary of the figures for all three unit configurations at the fabrication and berth erection workstations is given in Fig.(12). This data can be examined to identify areas of high work content, e.g. beam/girder gusset plates.

The total costs of labour plus material for each configuration, presented by workstation, is given in Fig. (13). The total cost for the 3, 6, and 9 unit configurations are £150,685 £155,471 and £156,746, respectively indicating that over the midship region the 3-unit configuration minimises cost. Then providing the shipyard's handling facilities are adequate, a 3-unit arrangement is to be preferred and can save 4% of the cost of a 9-unit configuration. A similar study by Bong (5) for bulk carriers using Korean data gave a similar result showing that a reduction in the number of units from 8 to 4 reduced costs by 5%.

Effects of Changing the Length of productive Day

One of the most obvious factors which influences productivity levels is the length of the period during which work is carried out. The benefits to be gained can be readily assessed by means of a sensitivity study in which the appropriate value is systematically varied. The original data used in these examples is shown in Table 3. To demonstrate the effect of varying the length of productive day the original figure of 5 hours was changed by + 1 hour. The effects are shown in the tables in Fig.(13). It can be seen that a one-hour increase in the productive day produces a saving of approximately £13,000, whereas a decrease of one-hour adds about £20,000 or 25%.

These changes refer only to different build strategies. An even more valuable application is to look at:
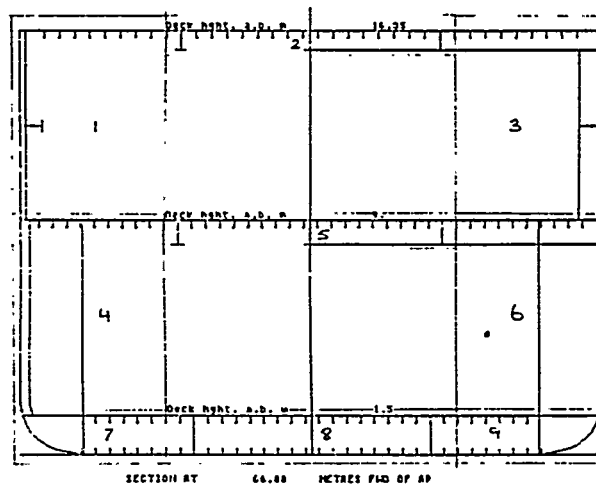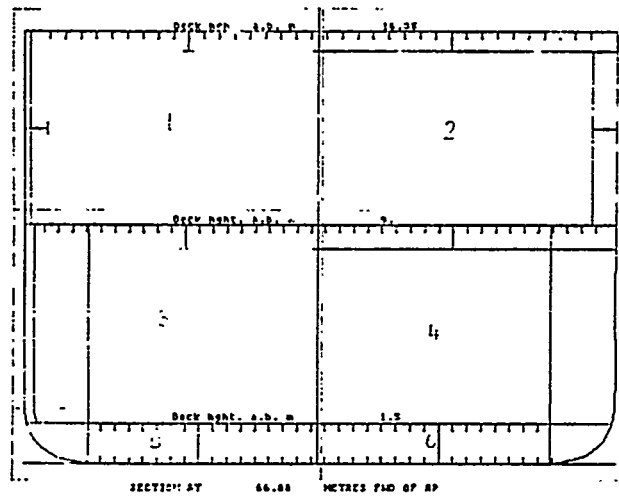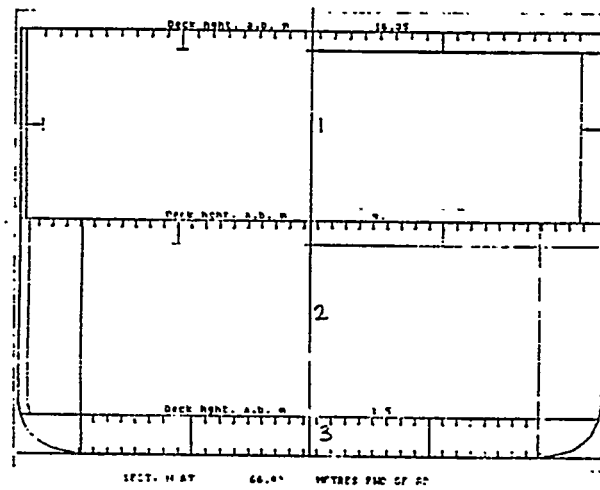
FIG (10). ALTERNATIVE UNIT CONFIGURATIONS

```
|-----------------------------------------------------------------------------------------------------|
| Unit No : 1        ||    Work Content and Material Cost Parameters                                   |
|      Unit Type     ||------------------------------------------------------------------------------- |
| C-UNIT (Deck + 2 Sides)|| PPAJL | PFJL  | UFJL  | BEJL  | No.  | THKs| NETT    | GROSS | GD |
| Items (3y Panel)    ||  (m)  |  (m)  |  (m)  |  (m)  |Parts| (mm)| WT.(T) | WT.(T)|    |
|=====================================================================================================|
|-----------------------------------------------------------------------------------------------------|
|      Data For Deck No. 2 and Below                                                                  |
|-----------------------------------------------------------------------------------------------------|
| DECK PLATE          || 71.12|  0.00|  0.00| 23.00|   8 | 16.0| 29.35| 30.52| NA |
| DECK BEAMS          ||  4.40|184.00|  0.00|  0.00|   8 | 12.0| 12.82| 13.33| NA |
| DECK LONGITUDINALS  ||  0.00|345.44|  0.00| 10.20|  34 | 11.0| 11.74| 12.21| NA |
| DECK GIRDERS        ||  0.00| 60.96|  0.00|  2.85|   3 | 10.0|  2.37|  2.46| NA |
| BM/LONG'L INTER     ||  0.00|  0.00| 20.40|  0.00| 136 | 11.0|  0.00|  0.00| NA |
| BM/GRDR INTER (F)   ||  0.00|  0.00| 22.20|  0.00|  12 | 10.0|  0.00|  0.00| NA |
| BM/GRDR INTER (B)   ||  0.00|  0.00|  4.80|  0.00|  12 | 12.0|  0.00|  0.00| NA |
| BM/GRDR GUSSETS     ||  0.00|  0.00| 33.60|  0.00|  48 | 25.0|  0.58|  0.60| NA |
| BM/TRIP BRACKETS    ||  0.00| 24.00|  0.00|  0.00|  32 | 12.0|  0.17|  0.18| NA |
| S.SHELL PL (FLAT)   || 20.32|  0.00|  0.00| 17.41|   3 |  9.5|  5.50|  5.72| NA |
| D.FRAMES (SRT)      || 26.40| 26.40|  0.00|  3.10|   4 | 12.0|  3.93|  4.08| NA |
| S.FRAMES (SRT)      ||  0.00| 88.20|  0.00|  1.44|  12 | 10.0|  2.24|  2.33| NA |
| DECK/S.SHELL INTER  ||  0.00|  0.00| 10.16|  0.00|   1 | 16.0|  0.00|  0.00| NA |
| DP.F/BEAM INTER     ||  0.00|  0.00|  4.80|  0.00|   4 | 25.0|  0.00|  0.00| NA |
| BEAM/S.SHELL INTER  ||  0.00|  0.00|  4.40|  0.00|   4 | 12.0|  0.00|  0.00| NA |
| DP.F/BEAM BRACKETS  ||  0.00|  0.00| 13.60|  0.00|   4 | 25.0|  1.13|  1.18| NA |
| S.SHELL PL (FLAT)   || 20.32|  0.00|  0.00| 17.41|   3 |  9.5|  5.50|  5.72| NA |
| D.FRAMES (SRT)      || 26.40| 26.40|  0.00|  3.10|   4 | 12.0|  3.93|  4.08| NA |
| S.FRAMES (SRT)      ||  0.00| 88.20|  0.00|  1.44|  12 | 10.0|  2.24|  2.33| NA |
| DECK/S.SHELL INTER  ||  0.00|  0.00| 10.16|  0.00|   1 | 16.0|  0.00|  0.00| NA |
| DP.F/BEAM INTER     ||  0.00|  0.00|  4.80|  0.00|   4 | 25.0|  0.00|  0.00| NA |
| BEAM/S.SHELL INTER  ||  0.00|  0.00|  4.40|  0.00|   4 | 12.0|  0.00|  0.00| NA |
| DP.F/BEAM BRACKETS  ||  0.00|  0.00| 13.60|  0.00|   4 | 25.0|  1.13|  1.18| NA |
|-----------------------------------------------------------------------------------------------------|
| Totals              || 168.96|843.60|146.92| 79.96|     |     | 82.62| 85.93|    |
|-----------------------------------------------------------------------------------------------------|
```

PPAJL = Piece Parts Assembly Joint Length
PFJL = Panel Fabrication Joint Length
UFJL = Unit Fabrication Joint Length
BEJL = Berth Erection Joint Length

FIG (11a). TABLE OF JOINT LENGTHS FOR 'C' UNIT

UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	Structural Items (Within Unit)	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
	FABRICATION						
1	DECK PLATE	40.94	46.27	151.81	835.0	2.13	5.17
1	DECK BEAMS	234.70	265.21	870.21	4786.2	4.62	67.88
1	DECK LONGITUDINALS	65.40	73.91	242.50	1333.8	0.70	20.66
1	DECK GIRDERS	30.31	34.25	112.39	618.1	1.84	47.44
1	BM/LONG'L INTER	26.50	29.94	98.25	540.4	4.82	0.00
1	BM/GRDR INTER (F)	28.81	32.56	106.92	587.5	4.81	0.00
1	BM/GRDR INTER (B)	4.99	5.64	18.51	101.8	3.86	0.00
1	BM/GRDR GUSSETS	41.68	47.10	154.56	850.1	4.60	267.88
1	BM/TRIP BRACKETS	1.53	1.73	5.67	31.2	0.24	33.44
1	S.SHELL PL (FLAT)	12.24	13.84	45.40	249.7	2.23	8.26
1	D.FRAMES (SRT)	17.01	19.22	63.06	346.8	1.19	16.06
1	S.FRAMES (SRT)	18.00	20.33	66.72	367.0	0.76	29.74
1	DECK/S.SHELL INTER	13.92	15.73	51.62	283.9	5.08	0.00
1	DP.F/BEAM INTER	8.26	9.34	30.64	168.5	6.38	0.00
1	BEAM/S.SHELL INTER	4.74	5.36	17.59	96.7	4.00	0.00
1	DP.F/BEAM BRACKETS	7.55	8.53	27.99	154.0	2.06	24.68
1	S.SHELL PL (FLAT)	12.24	13.84	45.40	249.7	2.23	8.26
1	D.FRAMES (SRT)	17.01	19.22	63.06	346.8	1.19	16.06
1	S.FRAMES (SRT)	18.00	20.33	66.72	367.0	0.76	29.74
1	DECK/S.SHELL INTER	13.92	15.73	51.62	283.9	5.08	0.00
1	DP.F/BEAM INTER	8.26	9.34	30.64	168.5	6.38	0.00
1	BEAM/S.SHELL INTER	4.74	5.36	17.59	96.7	4.00	0.00
1	DP.F/BEAM BRACKETS	7.55	8.53	27.99	154.0	2.06	24.68
	SUMMARY TOTAL	638.3	721.3	2366.8	13017.3	2.04	28.65

FIG (11b). TABLES OF WORK CONTENT AND LABOUR COSTS FOR 'C' UNIT. AT FABRICATION WORKSTATIONS

4-14

3 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
FABRICATION							
1	C-UNIT (Deck + 2 Sides)	638.32	721.30	2366.78	13017.3	2.04	28.65
2	C-UNIT (Deck + 2 Sides 2	960.17	1142.60	3749.16	20620.4	2.04	33.84
3	DBLE BOTTOM TOTAL UNIT	1091.91	1299.27	4263.56	23449.6	2.73	46.39
	GRAND TOTAL	2690.4	3163.5	10379.5	57087.2	2.27	36.38

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
BERTH ERECTION							
1	C-UNIT (Deck + 2 Sides)	39.10	89.83	345.28	1899.0	6.64	0.00
2	C-UNIT (Deck + 2 Sides 2	42.54	182.54	701.63	3859.0	4.65	0.00
3	DBLE BOTTOM TOTAL UNIT	97.72	220.12	846.10	4653.5	5.26	0.00
	GRAND TOTAL	267.6	772.1	2967.8	16322.9	5.24	0.00

6 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
FABRICATION							
1	L.UNIT (Deck + Side)	333.52	350.19	1149.08	6319.9	1.94	27.49
2	L.UNIT (Deck + Side)	301.18	316.24	1037.66	5707.2	1.88	25.42
3	L.UNIT (Deck + Side + IH	501.05	531.11	1742.72	9584.9	1.85	30.67
4	L.UNIT (Deck + Side + IH	455.35	482.67	1583.75	8710.6	1.79	29.34
5	DB BILGE 2 S.GRDRS+CG	623.90	698.77	2292.82	12610.5	2.74	54.94
6	DB BILGE (2 S.GRDRS)	461.56	516.95	1696.23	9329.3	2.42	43.26
	GRAND TOTAL	2676.6	2895.9	9502.3	52262.5	2.11	34.64

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
BERTH ERECTION							
1	L.UNIT (Deck + Side)	45.63	105.81	406.71	2236.9	5.85	0.00
2	L.UNIT (Deck + Side)	43.77	101.28	389.30	2141.2	5.86	0.00
3	L.UNIT (Deck + Side + IH	49.04	150.49	578.45	3181.5	4.79	0.00
4	L.UNIT (Deck + Side + IH	46.55	144.38	554.97	3052.3	4.76	0.00
5	DB BILGE 2 S.GRDRS+CG	79.47	160.46	616.78	3392.3	5.21	0.00
6	DB BILGE (2 S.GRDRS)	67.62	138.21	531.26	2921.9	4.99	0.00
	GRAND TOTAL	529.2	1316.0	5058.3	27820.6	5.21	-

9 - UNIT LABOUR COST BREAKDOWN

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
FABRICATION							
1	L.UNIT (Deck + Side)	211.31	221.88	728.04	4004.2	1.89	26.35
2	Panel Unit	217.20	230.23	755.43	4154.9	2.07	27.52
3	L.UNIT (Deck + Side)	211.31	221.88	728.04	4004.2	1.89	26.39
4	L.UNIT (Deck + Side + IH	308.73	327.25	1073.80	5905.9	1.65	29.75
5	Panel Unit	337.28	357.52	1173.11	6452.11	2.26	30.35
6	L.UNIT (Deck + Side + IH	308.73	327.25	1073.80	5905.9	1.65	29.75
7	DB BILGE (1 S.GRDR)	277.30	335.53	1100.96	6055.3	3.44	58.03
8	DB BTM FLAT 2 S.GRDRS	528.87	666.38	2186.57	12026.1	2.50	50.85
9	DB BILGE (1 S.GRDR)	277.30	335.53	1100.96	6055.3	3.44	58.03
	GRAND TOTAL	2678.0	3023.5	9920.7	54563.9	2.22	36.16

SHIP UNIT No.	GENERIC UNIT TYPE	STANDARD W.CONT (MHRS)	INHERENT W.CONT (MHRS)	ACTUAL W.CONT (MHRS)	FAB LABOUR COST($)	W.CONT/ METRE (MHRS/m)	W.CONT/ TONNE (MHRS/T)
BERTH ERECTION							
1	L.UNIT (Deck + Side)	35.32	79.35	304.99	1677.4	6.03	0.00
2	Panel Unit	40.94	78.99	303.61	1669.8	4.76	0.00
3	L.UNIT (Deck + Side)	35.32	79.35	304.99	1677.4	6.03	0.00
4	L.UNIT (Deck + Side + IH	34.63	114.95	441.86	2430.2	4.60	0.00
5	Panel Unit	48.02	93.19	358.19	1970.0	4.72	0.00
6	L.UNIT (Deck + Side + IH	34.25	114.06	438.40	2411.2	4.59	0.00
7	DB BILGE (1 S.GRDR)	45.35	90.13	346.43	1905.4	5.16	0.00
8	DB BTM FLAT 2 S.GRDRS	79.48	176.44	678.18	3730.0	5.33	0.00
9	DB BILGE (1 S.GRDR)	45.35	90.13	346.43	1905.4	5.16	0.00
	GRAND TOTAL	550.3	1317.6	5064.7	27855.8	5.13	0.00

FIG (12). WORK CONTENT ESTIMATES

Global labour costs table for 3 UNITS.

Standard work content = 2958.0 Man Hours
Inherent work content = 3935.4 Man Hours
Nett weight   = 285.3 tonnes

	PAID day hours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	29.5	80.0	100.0	13347.3	5.50	73410.	46.8
CASE 1	7.5	6.0	35.4	80.0	100.0	11122.7	5.50	61175.	39.0
CASE 2	7.5	4.0	23.6	80.0	100.0	16684.1	5.50	91763.	58.5

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	150685.	507.00
CASE 1	4.2	297.2	260.	77275.	138450.	465.83
CASE 2	4.2	297.2	260.	77275.	169038.	568.74

Global labour costs table for 6 UNITS

Standard work content = 3205.8 Man Hours
Inherent work content = 4211.9 Man Hours
Nett weight   = 285.3 tonnes

	PAID day hours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	28.9	80.0	100.0	14560.6	5.50	80083.	51.0
CASE 1	7.5	6.0	34.7	80.0	100.0	12133.8	5.50	66736.	42.5
CASE 2	7.5	4.0	23.1	80.0	100.0	18200.7	5.50	100104.	63.8

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	155471.	544.94
CASE 1	4.2	297.2	260.	77275.	142124.	498.16
CASE 2	4.2	297.2	260.	77275.	175492.	615.11

Global labour costs table for 9 UNITS

Standard work content = 3228.7 Man Hours
Inherent work content = 4342.2 Man Hours
Nett weight   = 285.3 tonnes

	PAID day hours	PROD day hours	BUILD effcy %	YARD loading %	MAN level %	ACTUAL man hours	LABOUR rate pds/hr	LABOUR cost pound	GROSS mhr/t
ORIGINAL	7.5	5.0	29.0	80.0	100.0	14989.5	5.50	82442.	52.5
CASE 1	7.5	6.0	34.8	80.0	100.0	12491.2	5.50	68702.	43.8
CASE 2	7.5	4.0	23.2	80.0	100.0	18736.8	5.50	103053.	65.7

	SCRAP % of nett	GROSS wght tonne	MATRL pds/t rate	MATRL cost pound	LABOUR & MAT pound	GROSS pds/t Tot L&M
ORIGINAL	4.2	297.2	260.	77275.	156746.	549.41
CASE 1	4.2	297.2	260.	77275.	143005.	501.24
CASE 2	4.2	297.2	260.	77275.	177356.	621.65

FIG (13). COSTS OF ALTERNATIVE BREAKDOWNS

TABLE (3) . BASIS DATA USED IN SENSITIVITY ANALYSIS

<u>Total</u> cost variants menu
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1. Change labour rate (pounds/hour)	original value - 5.50
2. Change scrap (Percentage of **Gross**)	original value - 4.00
3. Change material cost (cost per tonne)	original value - 260.00
4. Change length **of paid working day (hrs.)**	original value - 7.50
5. Change length of productive day (hrs.)	original value - 5.00
6. Change general build efficiency (%)	original value - 30.48
7. Change yard loading (%)	original value - 80.00
8. Change Global Manning Level (%)	original value - 100.00

(i) alternative structural designs
(ii) alternative vessel arrangement

Under (i) the system can be used to examine for example different stiffener spacings, or single versus double hulls at upper decks. The latter arrangement would enhance ro-ro survivability in the event of a collision. Under (ii), alternative depths to each deck and double bottom can be examined. For example, beam-to-beam depth can be reduced by using shallower heavier beams retaining the same clear deck height for vehicles. The scantling and mass estimation program estimates the changes in steelmass and centre of gravity, while the cost estimating program compares the costs. The designer and builder now have potentially much more creative tools available.

FUTURE ENHANCEMENTS

The principles and methodology on which this work is based can be extended not only to other ship types but to other areas of ship production, in particular applications in the outfitting area. Some outfit manufacturing process data does exist and systems are in place which will facilitate further information to be collected thus enabling the processes to be realistically modelled. This in turn will allow more comprehensive analyses to be carried out. For example the addition of outfit to the system will allow a more representative model of modern shipbuilding processes to be used when considering build strategy, resource utilization and modular construction.

Extending the system to a wider range of ship types including warships is being considered. This would necessitate a different database to be constructed to account for the different standards associated with the building of naval vessels.

In the computing field the applications of transputers could bring about significant benefits. A parallel processing environment which permits multi-tasking has obvious advantages at the concept stage where a number of alternative proposals could be examined simultaneously.

Some recent work by the authors [g] has demonstrated the Artificial Intelligence can be used effectively at the concept design stage. Some of the techniques described in Ref.(9) could be used to enhance the cost estimating process, e.g. some form of automatic data feedback from the production departments for ships recently built could be used, via an expert system, to update the database and thus continually improve the system performance and reliability.

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